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REMOTE SENSING OF EARTH TERRAIN

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SEMI-ANNUAL PROGRESS REPORT

Under the sponsorship of the NASA Contract NAG5-270, we have published 2 books and 57 refereed journal and conference papers for the research on the remote sensing of earth terrain.

During the period March 1, 1986 to August 31, 1986, we have studied the Mueller matrix and polarization covariance matrix for polarimetric radar systems. The clutter is modelled by a layer of random permittivity, described by a three-dimensional correlation function, with variance, and horizontal and vertical correlation lengths. This model is applied, using the wave theory with Born approximations carried to the second order, to find the backscattering elements of the polarimetric matrices. It is found that 8 out of 16 elements of the Mueller matrix are identically zero, corresponding to a covariance matrix with four zero elements. Theoretical predictions are matched with experimental data for vegetation fields.

A general mixing formula is derived for discrete scatterers immersed in a host medium. The inclusion particles are assumed to be ellipsoidal. The electric field inside the scatterers is determined by quasistatic analysis, assuming the diameter of the inclusion particles to be much smaller than the wavelength. The results are applicable to general multiphase mixtures, and the scattering ellipsoids of the different phases can have different sizes and arbitrary ellipticity distribution and axis orientation, i.e., the mixture may be

isotropic or anisotropic. The resulting mixing formula is nonlinear and implicit for the effective complex dielectric constant, because the approach in calculating the internal field of scatterers is self-consistent. Still, the form is especially suitable for iterative solution. The formula contains a quantity called the apparent permittivity, and with different choices of this quantity, the result leads to the generalized Lorentz - Lorenz formula, the generalized Polder - van Santen formula, and the generalized coherent potential - quasicrystalline approximation formula. Finally, the results are applied to calculating the complex effective permittivity of snow and sea ice.

We have used the strong fluctuation theory to derive the backscattering cross sections. The study of the strong fluctuation theory for a bounded layer of random discrete scatterers is further extended to include higher order co-polarized and cross-polarized second moments. The backscattering cross sections per unit area are calculated by including the mutual coherence of the fields due to the coincidental ray paths and that due to the opposite ray paths which are corresponding to the ladder and cross terms in the Feynman diagrammatic representation. It is proved that the contributions from ladder and cross terms for co-polarized backscattering cross sections are the same, while the contributions for the cross-polarized ones are of the same order. The bistatic scattering coefficients in the second-order approximation for both the ladder and cross terms are also obtained. The enhancement in the backscattering direction can be attributed to the contributions from the cross terms.

A two-layer anisotropic random medium model is developed for the active and passive microwave remote sensing of ice fields. The dyadic Green's function for this two-layer anisotropic medium is derived. With a specified correlation function for the randomness of the dielectric constant, the backscattering cross sections are calculated with the Born approximation. It is shown that the depolarization effects exist in the single-scattering process. Treating sea ice as a tilted uniaxial medium, the observed strong cross-polarized

return in the bistatic scattering coefficients is successfully predicted from the theoretical model. It is also shown that the backscattering cross section of horizontal polarization can be greater than that of vertical polarization even in the half-space case. The principle of reciprocity and the principle of energy conservation are invoked to calculate the brightness temperatures. The bistatic scattering coefficients are first calculated and then integrated over the upper hemisphere to be subtracted from unity, in order to obtain the emissivity for the random medium layer. It is shown that both the absorptive and randomly fluctuating properties of the anisotropic medium affect the behavior of the resulting brightness temperatures both in theory and in actual controlled field measurements. The active and passive results match favorably well with the experimental data obtained from the first-year and the multiyear sea ice as well as from the corn stalks with detailed ground-truth information.

The Feynman diagrammatic technique is used to derive the Dyson equation for the mean field and the Bethe-Salpeter equation for the correlation or the covariance of the field for electromagnetic wave propagation and scattering in an anisotropic random medium. With the random permittivity expressed in a general form, the bilocal and the nonlinear approximations are employed to solve the Dyson equation and the ladder approximation to the Bethe-Salpeter equation. The mean dyadic Green's function for a two-layer anisotropic random medium with arbitrary three-dimensional correlation functions has been investigated with the zeroth-order solutions to the Dyson equation under the nonlinear approximation. The effective propagation constants are calculated for the four characteristic waves associated with the coherent vector fields propagating in an anisotropic random medium layer, which are the ordinary and extraordinary waves with upward and downward propagating vectors.

A three-layer random medium model is adopted to study the volume scattering effects for the active and passive microwave remote sensing of snow-covered ice fields [13]. We simulate the snow layer by an isotropic random medium and the ice layer by an anisotropic random medium. In snow, the fluctuation of the permittivity and the physical sizes of the granular ice particles are characterized by the variance and two correlation lengths. In ice, the anisotropic effect is attributed to the elongated structures and the specific orientations of the air bubbles, the brine inclusions, and other inhomogeneities. Two variances are required to characterize the fluctuations of the permittivities along or perpendicular to the tilted optic axis. The physical sizes of those scattering elements are also described by two correlation lengths.

Nonlinear EM wave interactions with the upper atmosphere have been investigated on the following subjects: (1) the simultaneous excitation of ionospheric density irregularities and earth's magnetic field fluctuations, (2) the electron acceleration by Langmuir wave turbulence, and (3) the occurrence of artificial spread F. While processes (2) and (3) can be caused only by HF waves, process (1) occurs with EM frequencies as low as in the VLF band and as high as in the SHF band.

Radio measurements of Total Electron Content (TEC) and optical detection of airglow variations show that large scale plasma patches appearing in the high latitude ionosphere have irregular structures, evidenced by the satellite phase and amplitude scintillations. Whistler waves, intense quasi-DC electric fields, atmospheric gravity waves, and electrojets are potential sources of various plasma instabilities. The role of thermal effects in generating ionospheric irregularities by these sources have been investigated. A model has been developed to explain the discrete spectrum of the resonant ULF waves that have been commonly observed in the magnetosphere. The resonant electron diffusion is suggested to be an effective saturation process of the auroral kilometric radiation. The

calculated intensity of the saturated radiation has a significantly lower value in comparison with that caused by the quasi-linear diffusion process as an alternative saturation process.

The vegetation canopy and snow-covered ice field have been studied with a three-layer model, an isotropic random medium layer overlying an anisotropic random medium. We have calculated the dyadic Green's functions of the three-layer medium and the scattered electromagnetic intensities with Born approximation. The backscattering cross sections are evaluated for active microwave remote sensing. The theoretical approach can be extended to derive the bistatic scattering coefficients. After integrating the bistatic scattering coefficients over the upper hemisphere and subtracting from unity, we can also compute the radiometric brightness temperatures for passive microwave remote sensing by invoking the principle of reciprocity.

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